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Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

U.S. Geological Survey Award No. G11AP20032

Element I & III

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ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/CISN) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

Crustal geophysics and seismicity in southern California

The geographical distribution of the (1981 to 2005) seismicity in southern California forms a ±150 km broad zone adjacent to the Pacific-North America plate boundary, ranging from depths of ~1 km to ~30 km, with the bulk of the focal depths in the range of 2 to 12 km. The distribution of the seismicity that includes both mainshock-aftershock sequences and background events is affected by both static and kinematic geophysical parameters of the crust. The static parameters include heat flow, topography, crustal density, Vp/Vs ratio, hypocentral fault-distance, and crustal thickness from receiver functions. The tectonic loading is represented by kinematic parameters such as the crustal shear strain rate field, and the dilatational strain rate field. In our analysis, we normalize the seismicity relative to the areal density of the range of values of each of the parameters. Most of the seismicity occurs in areas of average heat flow (Figure 1), low to intermediate topography, average Vp/Vs, and high late Quaternary fault density, and forms seismogenic zones that extend through the brittle crust. The location of late Quaternary faults, often described as zones of weakness, influences the geographical distribution of seismicity more than any other parameter. Although above or below average crustal properties such as high heat flow, thin crust, or very low Vp/Vs values exist, these properties only influence the spatial distribution of seismicity in a minor way. As an example, the Salton Trough area of low

topography, high heat flow, high Vp/Vs, high shear strain rate, and thin crust has distributed seismicity within a thin seismogenic zone. Also, somewhat surprisingly, areas of high topography, low heat flow, low Vp/Vs, low shear strain rate, and thick crust have low seismicity rates but a thin seismogenic zone. We determine an empirical relationship between heat flow and crustal thickness to show how the ~400°C temperature isotherm gradually deepens with crustal thickness and forms the base of the seismogenic zone for crustal thicknesses from 22 to 37 km. For crustal thickness ranging from 37 to 43 km, the ~250°C isotherm forms the base of the seismogenic zone, suggesting that seismic faulting in these regions is confined to the top of the upper crust (12 to 14 km), and thus does not accommodate plate motion.

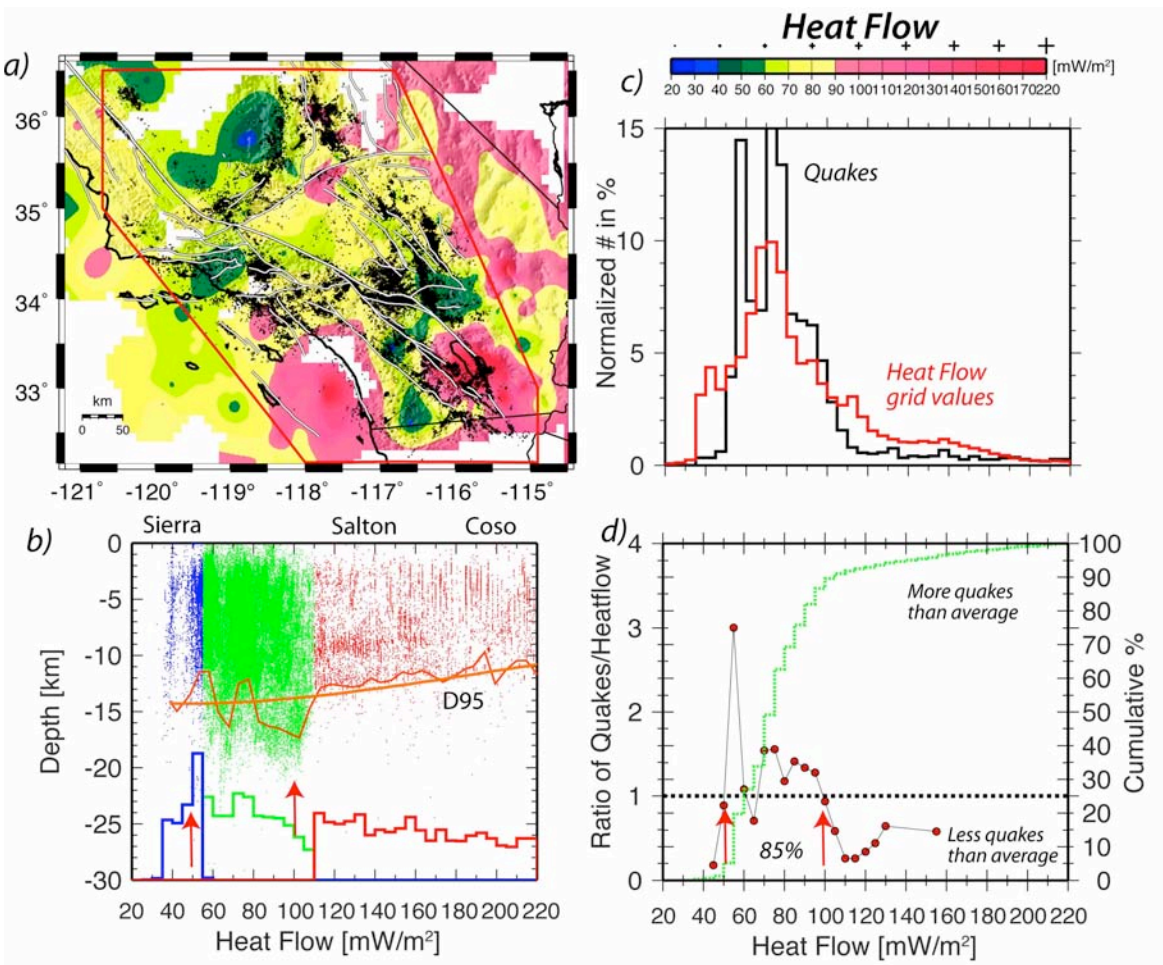

Figure 1. *Heat flow and seismicity. (a) Earthquakes of M≥1.8 are plotted on top of the heat flow for southern California within the study area outlined by the red polygon. (b) Each hypocenter is plotted at the respective focal depth and heat flow value interpolated from the map. Detailed and smooth versions of the 95% maximum seismicity depth contour are plotted in orange color. (Bottom) histograms separating the three ranges of heat flow values, 0-55 (blue), 55-110 (green), and 110-3000 (red) mWm^2, with y=log10(1.0+frequency percent) with full scale of 5.0. (c) Normalized histograms of quakes and 'heat flow values' for each 10 [mW/m^2] interval of heat flow. The abscissa is the same as in panel (d). (d) Ratio of the two histograms in c) per 10 [mW/m^2] interval in heat flow (curve with red dots), and cumulative number of quakes (green curve). The arrows indicate the range of heat flow where the percent (value shown in plot) of the seismicity occurs.*

Southern California (1981 to 2005) seismicity clusters near the late Quaternary faults, which accommodate the relative Pacific and North America plate movement in the crust with typically average geophysical properties. The proximity of seismicity, including mainshock-aftershock sequences and background seismicity, to late Quaternary faults has a much stronger influence on the distribution of seismicity than other geophysical crustal parameters, such as heat flow, isostatic gravity, shear strain rate, and volumetric strain rates.

Variations in crustal thickness cause different scales of localization of deformation. Only sparse seismicity is present if the crust is thick, or dense with minimal quartz content, or the elevation high. This is consistent with crustal faults not extending through the thick crust of the major mountain ranges, and instead forming through going crustal faults at lower elevations. Similarly, if the crust is thin, the heat flow is very high, and topography is low, the seismogenic zone is also thin. The kinematic volumetric strains as well as modeling of the dilatational strain rate field favor earthquakes in extensional regimes, with some earthquakes in the compressional regime only if the strain rate is high enough.

The crustal isotherms increase in depth with increasing crustal thickness. The ~400°C isotherm forms the base of the seismogenic zone for crustal thickness from 22 to 37 km. At greater depths, 37 to 43 km, the ~250°C isotherm forms the base of the seismogenic zone. The deepening of the isotherms with increasing crustal thickness, and the systematic shallowing in focal depths at depths greater than 37 km is caused by the increased crustal thickness and possibly absence of fluids. Thus earthquakes in the shallow part of very thick crust may signify other processes than plate tectonic motion (Hauksson, 2011).

Computing a large refined catalog of focal mechanisms for southern California (1981 – 2010): Temporal Stability of the Style of Faulting

Using the HASH method (Hardebeck and Shearer, 2002, 2003), we calculate focal mechanisms for earthquakes that occurred in the southern California region from 1981 to 2010. When available, we use hypocenters refined with differential travel-times from waveform cross-correlation. We apply grid search to determine the best-fitting double-couple focal mechanism solution. The data consist of both the P-wave first motion polarities and the S/P amplitude ratios computed from three-component seismograms. We process data from more than 480,000 earthquakes, and analyze the statistical features of the whole data set. As more S/P amplitude ratios become available after 2000, the average nodal plane uncertainty decreases significantly compared with solutions that include only P-wave polarities. We filter a preliminary data set with criteria associated with mean nodal plane uncertainty and azimuthal gap, and obtain a high quality catalog with approximately 179,000 focal mechanisms. In general the parameters of the focal mechanisms have been stable during the three decades (Figure 2). The dominant style of faulting is high angle strike-slip faulting with the most likely P axis centered at N5°E. For earthquakes of $M < 2.5$, there are more normal faulting events than reverse faulting events while the opposite holds for $M > 2.5$ events. A comparison of 23,000 common earthquakes shows our results generally agree with the focal mechanism catalog obtained by Hardebeck and Shearer (2003). Using 210 moment tensor solutions in Tape et al (2010) as benchmarks, we compare the focal plane rotation angles of common events in the catalog. 70% of common earthquakes in both catalogs match well, with rotation angles less than the typical nodal plane uncertainty in the total first motion and S/P ratio mechanisms. The common events with relatively large rotation angles are either located around the edge of the SCSN network or poorly recorded (Yang et al., 2012).

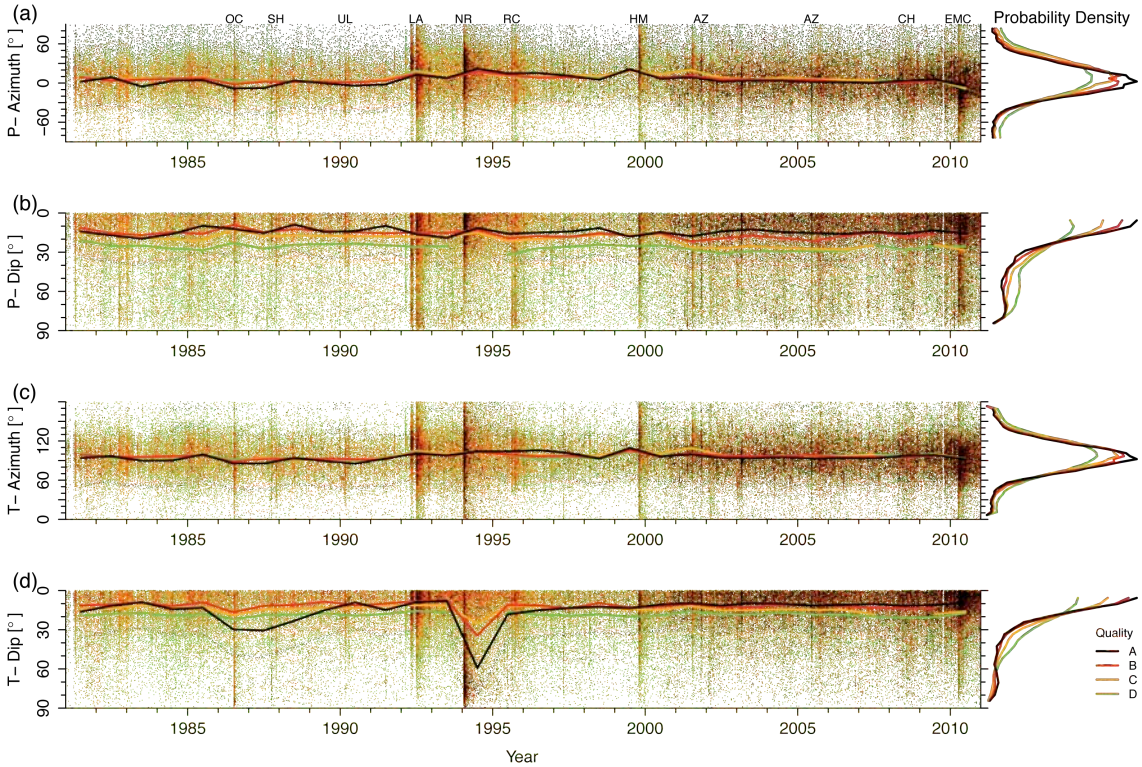

Figure 2. *The temporal variations of P- azimuth (a), P- dip (b), T-azimuth (c), and T- dip (d) for quality A (black), B (red), C (yellow) and D (green) data in the refined focal mechanism catalog. In each subplot, the four curves represent the annual median value for different qualities, and the probability density distribution of each parameter over time for the four qualities are illustrated at the right side. The legend of colors lies at the bottom right corner. In (a), significant events in southern California are marked chronologically with "OC" (1986 Oceanside M_L5.4), "SH" (1987 Superstition Hills M_W6.6), "UL" (1988 Upland ML4.7), "LA" (1992 Landers M_W7.3), "NR" (1994 Northridge M_W6.7), "RC" (1995 Ridgecrest M_L5.4), "HM" (1999 Hector Mine M_W7.1), "AZ" (2001 Anza M_L5.1), "AZ" (2005 Anza M_W5.2), "CH" (2008 Chino Hill M_W5.4), and "EMC" (2010 El Mayor-Cucapah M_W7.2) on the top.*

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ABSTRACTS FOR RECENT ORAL, REPORTS, OR POSTER PRESENTATIONS

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